On two remarkable rain-bursts in Bengal; and some of the more prominent features of the monsoon season in Northern India in 1902.—*By* C. Little.

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Part I.

The south-west monsoon is a subject of enduring interest to many, not only to those who are continuous residents in the plains of India, or to those who are interested in raw products, but to all professional meteorologists, and to many other scientific men, whose work dovetails in with meteorological investigations. I make no claim to belong to any of these classes except the first, but my official duty as storm-warning officer for ports in the Bay of Bengal, has made it necessary for me to try and follow others in their advances in the direction of explaining complicated atmospheric changes. Any attempt by me to go beyond the *rôle* of follower has been either with the purpose of educating myself or merely as a pastime, and in either case it is not likely that it will be much, or any advantage to others to know what I have been studying, or what conclusions I have come to.

In my position of follower I have one strong belief which is, of course, a not uncommon belief, and it is that much of the weather in Northern India during the monsoon season depends on storms, which develop in the Bay of Bengal, or to be on the safe side, which enter India from the Bay. I have another belief which may not be so common, *viz.*, that, in one important respect intimately connected with the character of the monsoon, the behaviour of these storms is as yet a mystery. My main object in offering this brief paper for publication is that, by showing my ignorance others may be induced to supply the necessary information, or that if that information is not available, the collection of meteorological statistics may be more specially directed so as to meet a most important demand.

The difficulty I have felt is, how to account for the line of advance of storms (the word here meaning any cyclonic disturbance, slight or severe), while moving over the Bay, or the part of the country, which they may devastate or enrich. The past few years appear to me to have cast into strong relief the importance of having this matter placed, if possible, beyond question, so that the direction of advance may not only be accountable for after the event, but may be capable of exact forecast several days before. The importance of what is called the recurving of cyclonic storms was shown in 1899, when not a single depression entered India from the Bay but recurved over Central India, and as

every one will remmember the general distribution of rainfall in that year was great scarcity in the west and abundance in the east. The past monsoon season has been even more rich in evidence, in favour of the enquiry, which I here suggest, being one of first class importance.

The recurving of cyclonic disturbances, is not the only important matter of enquiry which a discussion of the past monsoon season brings to the surface. The disturbed weather which extended along the Himalayas on two occasions appears to me to indicate the direction in which the enquiry as to recurving should be made. These disturbances were the immediate cause of the two rain-bursts in Bengal, and I have on that account used them as a title for this paper. In what follows I have given small tables containing the more important meteorological statistics collected at the time of their occurrence and I have endeavoured to show how they serve to divide the monsoon season into periods which have important characteristics as regards the recurving of storms from the Bay and of the rainfall distribution in Northern India. No one who gives any consideration to such matters can have forgotten the famine cloud that was hanging over North-Western and Central India, in the early part of August, and the rapidity with which that foreboding vanished, when the storms from the Bay moved towards the area of drought.

Some Calcutta people may remember the change that occurred in the weather here on the 30th June. On that date a very trying period of hot muggy weather came to an end, and there began, at last, what had all the appearance of the south-west monsoon.

If there should be any doubt in the minds of my Calcutta friends as to what happened here on that date, I am sure residents of Benares will remember the relief they must have experienced, not on the 30th June, but on the 2nd July, that is, two days later, when their excessive temperature gave place to the comparative coolness of the south-west monsoon. The interval of two days between these occurrences shows one of the points which I wish to make out, *viz.*, that the change progressed from east to west. No one, I think will be likely to challenge that statement because it is accepted by everyone that south-west monsoon conditions gradually extend from the head of the Bay north-westward into Northern India. The other point which I wish to make, and which may not be readily accepted, is that the disturbance to which that change of weather was due, began in the north-east of India, and while progressing westward also extended southward over Bengal Proper in the first instance, then over Orissa and on to the Circars. It was even felt in Arakan and Madras though not very noticeably.

Of the occurrences accompanying this wave of change, which

passed over Bengal, one of the most noticeable on the meteorological record of the time is the heavy rainfall in Bengal Proper, between 8 A.M. on the 29th, and 8 A.M. on the 30th June. It appears in the record as rainfall of the 30th June.

I may, perhaps, be allowed to digress here for a moment to point out the difficulty, which I shall refer to later on, in establishing the sequence of events in atmospheric matters. The only record of such events is what the observers note at certain fixed hours—mostly 8 A.M., supplemented at a few places by observations at 4 P.M. If any change passes so rapidly over the land that it is completed within the 24 hours, between 8 A.M. of one day, and 8 A.M. of the next, it appears, as a simultaneous change and at times, an important part of the change is lost altogether. For instance, when a cyclone of small extent passes over an observatory the rapid fall of pressure during the approach of the central area and the rapid rise, after its passage, may occur in a few hours, and neither will be shown by the 8 A.M. record of that station, unless the passage occurs about that hour. For that reason, the pressure record of a disturbance, with a high rate of progress, is of less value in a historical survey than are those for temperature and rainfall. It would be a very awkward circumstance if the rain which falls, say in the afternoon, were to evaporate before it could be measured next morning. But the rainfall remains and though some rise of temperature occurs after the passage of a disturbance the recovery is slower than that of pressure, more especially if there should be a good deal of cloud at the time. Because of this difficulty as regards the record of pressure changes I rely more on the rainfall and temperature changes to prove the progressive motion from north to south for the disturbance which accompanied and no doubt caused the rainfall of the 30th June.

The second disturbance with which the rain-burst of the 11th August was associated was no less remarkable than the first, but it was less striking to the ordinary observer because there was not the same reversal of temperature. In one respect it was even more noticeable and that was as regards the pressure changes which in this case, strongly support the view that the disturbance entered India from Thibet. A reference to the Indian Daily Weather Report, will show that the fall of pressure preceding the June rainfall, occurred almost simultaneously over the whole of India so that pressure changes alone would not be sufficient to prove that the disturbance did not come from some other direction, from the Bay of Bengal for example, but the pressure changes preceding the August rainfall leave no room for doubt that that disturbance did not originate over the Bay. The fall of pressure began in the north-eastern Himalayas and from there, extended

westward and southward. The southerly element in this progressive movement was less marked in the second than in the first disturbance, as shown by both pressure and temperature changes.

The explanation of the weather changes for the periods represented for the purpose of this paper by the 30th June and the 11th August appears to be that just previous to these dates, depressions were crossing Thibet towards the Himalayan range, the first moving in a south-westerly, and the second in an almost due westerly direction. These depressions on reaching the Himalayas became to a certain extent broken up, more especially the former whose direction of motion had been almost perpendicular to the range of high hills. Owing to the comparatively small height of the hills to the north of Assam, a disturbance of some intensity entered that province and moving south-westward caused the rainfall in Assam and Bengal. The higher hills in Nepal, formed a more serious obstacle to the progress of the general disturbance, and that may be the reason why on both occasions the changes appear to have been delayed in Bihar and the United Provinces. The fact that the depressions had to pass over a range of hills extending in places to between twenty and thirty thousand feet, adds greatly to the difficulty of establishing continuity in the changes that occurred. What adds still further to the difficulty is that when a cyclonic storm encounters a range of hills of height sufficient to cause disintegration of the cyclonic system of air motion, local storms with large irregular changes of pressure and temperature and with irregular rainfall generally occur. In almost every case where a cyclonic storm moves northwards from the Bay of Bengal towards the Himalayas the storm breaks up very suddenly on reaching the hills, and instead of a well defined depression with cyclonic winds we find in a few hours a uniform distribution of pressure with numerous thunderstorms, it may be along the whole line of the Himalayas. Judging by what one observes of these storms, from the southern side of the range of hills it is very improbable that weather becomes disturbed in Thibet after a storm from the Bay of Bengal disappears amongst the hills. But that is not a sufficient reason for arguing that a cyclonic storm may not cross the Himalayas from Thibet into India. In the first place the Thibetan storm is at a high altitude, because of the Central Asian plateau, and a second reason is that the obstacle which the hills present, to the progress of a storm, from the Thibetan side is not nearly so serious as to storms from the south. There would be more or less isolated peaks to pass, instead of the solid wall, formed by the lower ranges up to 10,000 feet, surmounted by the peaks.

Among the general conclusions given in the *Monthly Weather*

Review for June, 1902, issued by the Meteorological Reporter to the Government of India, and Director-General of Indian Observatories, and suggested by the discussion of the atmospheric conditions in June in Europe, Asia, Africa, Australia, and the adjoining seas, the following occur:—

(1) "That conditions in India may be sometimes largely conditioned by actions taking place in the Central Asian areas, and that occasionally these actions extend over the greater part of Europe and Asia."

(3) "That these actions are largely modified by the barrier of the Himalayas and seem to spread more readily southwards through the gaps in the range."

These conclusions may I think be interpreted, as giving general support to my assumption that it is possible for a storm to cross the Himalayas into India from Thibet; but as regards my statement, that the depression moved towards India from a north-easterly direction, the *Monthly Weather Review* takes up an entirely different position. Discussing the changes of the 28th June it is there stated that "Large and important changes occurred on this day" and subsequently "It hence seems probable that the main centre of the action was near Gilgit, and that it extended almost up to Lake Balkash on the north, to Chitral on the west (where pressure was steady) and on the south over the greater part of India. It is impossible to further define the scope of the action for no data are available for the regions to the east of Gilgit. The fact, however, that the fall in Upper Assam was only moderate seems to indicate that the action did not extend far eastwards into Thibet."

What the comparatively small readings on that date in Assam appear to me to indicate is, that the wave of change had passed rapidly over Thibet, that the 8 A.M. pressure readings on the 28th in the north-east included some part of the recovery which had, by that time, commenced in the east; and that it had not reached the neighbourhood of Gilgit, etc. The great rapidity with which that change of pressure occurred is shown by the almost uniform fall over India, as given by the pressure readings at 8 A.M. of the 28th. The main result is that the pressure changes on that occasion give little or no indication of the direction of advance of the disturbance and that if there were no confirmatory evidence in favour of a westerly movement from other sources reliance would have to be placed on temperature and rainfall only. But the storm of the 11th August and adjoining days shows beyond all question, that that depression moved from east to west, and as in all other respects there was a striking resemblance between the two storms

it appears to me to be an established fact that the depression accompanying the rainfall of the 11th June passed over Thibet in a westerly or south-westerly direction, and that at 8 A.M. on the morning of the 28th, the region of Gilgit was near the front of the advancing wave.

Before commenting separately on the information regarding these storms preserved in the meteorological records, I will again point out that from whatever direction the storms entered Northern India, it was not from the Bay of Bengal. For several days before and after the two dates, mentioned above, weather was unusually quiet over the Bay, and in one respect was in striking contrast to what is usual in disturbed weather. At Diamond Island the most exposed of the observatories on the sea coast easterly winds of greater or less strength are an invariable accompaniment of disturbance. During the two periods of disturbance the direction was westerly day after day, which would indicate that weather was more probably disturbed over the south of Burma, than over the Bay, that is, if there were any disturbance in that region. The unusually low wind velocity at Diamond Island is sufficient in itself to prove that there was disturbance, neither over the Bay nor in Burma, until some days after the events under discussion.

Part II.

The following tables give in the form which appears to me most convenient for purposes of comparison, the data for the storms in succession. When weather is unsettled changes at different observatories are often very irregular more especially when local storms are frequent as appears to have been the case on both of these occasions. I have therefore given the average change for divisions containing four to six observatories or even more. The number of stations for each province or division is given in the rainfall tables.

Storm of June 30th.

The following tables I (*a*) and II (*a*) give the pressure changes from June 27th to July 5th, and the variation from the normal in Assam, Bengal Proper, and on the northern coasts of the Bay, arranged with the view of showing the southerly movement of the disturbance. As I have already stated the pressure change is practically useless for this purpose in the case of the June storm because it extended over India with great rapidity. The fall on the 28th was general and it continued in the north on the 29th. The recovery began on the 30th and extended from Assam and Bengal Proper to Orissa on the 1st July, practically the only evidence of south-westerly movement, afforded by the table. Table II (*a*) shows that pressure was relatively high on the 27th June, and that

there was continued excess, over the area represented, throughout the period except in Bengal Proper and Assam on the 29th June, and the Burma coast on the 2nd July. If the smallest excess or largest defect be selected for these divisions it will be found in the column of the 29th for Assam and Bengal Proper, of the 30th for Orissa, and of later dates for the Circars, Akyab, and Diamond Island. The relatively small excess on the 5th in the Circars and at Diamond Island is due to a cyclonic storm which began in the south of the Bay about that time.

TABLE I (*a*).

Giving the pressure change daily from June 27th to July 5th, arranged to show the southward movement of the disturbance.

	June 27	June 28	June 29	June 30	July 1	July 2	July 3	July 4	July 5
Assam ...	−·012″	−·080″	−·026″	+·041″	+·006″	−·013″	+·038″	+·053″	+·024″
North Bengal	−·009	−·073	−·083	+·096	−·006	−·009	+·027	+·040	+·029
East Bengal...	+·003	−·075	−·032	+·060	−·025	−·021	+·005	+·087	+·018
South-West Bengal ..	+·002	−·081	−·042	+·037	+·027	−·024	+·012	+·075	+·004
Orissa ...	+·014	−·045	−·032	−·006	+·027	−·028	+·005	+·032	+·028
Circars ...	+·031	−·028	−·008	+·002	−·019	+·002	−·024	+·003	−·004
Akyab ...	−·001	−·043	000	+·005	−·023	−·012	+·017	+·073	−·019
Diamond Island	+·038	−·025	−·012	−·015	+·011	−·044	+·024	+·008	+·004

TABLE II (*a*).

Giving the pressure variation from the normal from June 27th to July 5th, arranged to show the southward movement of the disturbance.

	June 27	June 28	June 29	June 30	July 1	July 2	July 3	July 4	July 5
Assam ...	+·111″	+·034″	−·002	+·045″	+·047″	+·029″	+·055″	+·112″	+·139″
N. Bengal ...	+·115	+·04	−·041	+·049	+·047	+·036	+·064	+·108	+·133
East Bengal...	+·116	+·039	−·001	+·063	+·040	+·016	+·025	+·109	+·127
South-West Bengal ...	+·123	+·050	+·010	+·041	+·058	+·031	+·045	+·124	+·126

TABLE II (*a*).—*Contd.*

	June 27	June 28	June 29	June 30	July 1	July 2	July 3	July 4	July 5
Orissa ...	+·130	+·082	+·043	+·035	+·064	+·038	+·044	+·081	+·110
Circars ...	+·100	+·070	+·061	+·062	+·042	+·041	+·018	+·020	+·015
Akyab ...	+·085	+·041	+·040	+·044	+·020	+·007	+·023	+·096	+·077
Diamond Island	+·071	+·044	+·031	+·015	+·025	−·020	+·003	+·010	+·013

Tables III (*a*) and IV (*a*) give the temperature change and variation from the normal for the same provinces and divisions as tables I (*a*) and II (*a*), prepared in the same way and with the same purpose, *viz.*, to show the southward movement of the wave of disturbance. To assist the eye I have had the larger changes and the larger variations printed in bolder type. It will be readily seen that the rapid fall of temperature began in Assam and North Bengal on the 29th June, in East Bengal on the 30th, in South-West Bengal and Orissa on July 1st, and in the Circars on the 2nd. There is here clear evidence that a wave of falling temperature proceeded from North-East India in a southerly direction beginning about the 29th June, and reaching the more southern districts three days later. Akyab and Diamond Island felt the change later and not to the same extent, as might be expected from there being a westerly element in the movement indicated by subsequent tables.

From Table IV (*a*) it will be seen that mean defect in Assam was 5°·7 on June 30th, about 5° over the whole of Bengal Proper on July 1st, 4°·3 in Orissa on the 2nd, 3°·1 in the Circars on the 3rd, and 4°·6 at Akyab on the 4th, while at Diamond Island there was a moderate to large excess throughout the period.

It is impossible to say whether the fall of 1°·5 at Diamond Island on the 5th is connected with the wave of falling temperature so clearly indicated as proceeding from the north-east or with the cyclonic disturbance which began over the south of the Bay about that date.

TABLE III (*a*).

Giving the temperature change daily from June 27th to July 5th, arranged to show the southward movement of the disturbance.

	June 27	June 28	June 29	June 30	July 1	July 2	July 3	July 4	July 5
Assam... ...	+2·4°	−0·2°	**−2·7°**	−3·2°	**+3·3°**	+1·3°	+0·8°	+0·5°	−1·6°
North Bengal ...	+2·5	−1·2	−1·8	**−2·3**	−1·6	**+4·4**	−0·2	−1·5	+1·8
East Bengal ...	+0·2	+1·0	−0·7	**−4·2**	−2.2	**+4·1**	+0·3	−1·6	+0·8
South-West Bengal	−1·1	+1·5	+0·6	−1·3	**−7·3**	**+3·6**	+1·8	−2·0	−2·6
Orissa	+2·2	−0·7	+0·9	+0·3	**−5·6**	−3·5	**+6·6**	+0·6	−3·6
Circars ...	−0·5	−3·2	+1·2	−1·0	+1·0	**−4·4**	−0·4	**+4·1**	+0·1
Akyab... ...	−0·8	+1 0	−0·2	−2·3	0·0	+0·8	**−2·3**	−2·3	**+3·8**
Diamond Island ..	+1·8	+0·5	+0·5	+0·2	+0·5	0·0	−0·1	+0·7	−1·5

TABLE IV (*a*).

Giving the temperature variation from the normal from June 27th to July 5th, arranged to show the southward movement of the disturbance.

	June 27	June 28	June 29	June 30	July 1	July 2	July 3	July 4	July 5
Assam ...	+0·8°	+0·3°	−2·0°	**−5·7°**	−2·9°	−0·5°	+0·7°	+0·4°	−0·9°
North Bengal ...	+2·2	+1·2	−0·8	−3·1	**−5·5**	−0·7	−1·3	−2·7	−0·4
East Bengal ...	+1·2	+2·2	+1·5	−2·7	**−5·0**	−0·9	−0·5	−2·1	−1·2
South-West Bengal	+2·2	+3·8	+4·5	+3·3	**−4·0**	−0·2	+1·7	−0·2	−2·7
Orissa... ...	+4·3	+3·3	+4·7	+5·1	−0·4	**−4·3**	+2·6	+2·7	−1·3
Circars ...	+3·8	+0·6	+1·7	+0·6	+1·6	−2·8	**−3·1**	+1·2	+1 5
Akyab ...	+0·8	+1·9	+1·6	−0·8	−0·8	0·0	−2·3	**−4·6**	−0·8
Diamond Island ...	+1·6	+2·1	+2·6	+2·9	+3·4	+3·4	+3·2	+4·0	**+2·5**

Tables V (*a*) to VIII (*a*) are arranged to show the westerly movement of the disturbance and give the pressure and temperature changes and variations for Northern India from Assam on the east to the Punjab and Kashmir on the west.

Table V (*a*) shows that the fall of pressure was general over Northern India on the 28th and on the 29th, and that the changes on those days give no indication of progressive movement; but on the 30th the recovery is shown as almost complete in Assam and North Bengal; partly complete in Bihar, beginning in the United Provinces and not yet begun in the Punjab. That is the only clear indication, of the westerly progressive movement given by the pressure changes.

TABLE V (*a*).

Giving the pressure change daily from June 27th to July 5th, arranged to show the westward movement of the disturbance.

	June 27	June 28	June 29	June 30	July 1	July 2	July 3	July 4	July 5
Assam ...	−·012″	−·080″	−·026″	+·041″	+·006″	−·013″	+·038″	+·053″	+·024″
North Bengal	−·009	−·073	−·083	+·096	−.006	−·009	+·027	+·040	+·029
Bihar ...	−·020	−·085	−·064	+·069	+·041	+·032	−·009	+·032	−·021
United Provinces ...	−·026	−·096	−·055	+·015	+·082	−·013	+·019	+·031	−·031
Punjab ...	−·022	−·117	−·061	−·008	+·028	−·030	+·091	+·051	−·017
Srinagar, etc.	−·006	−·093	−·045	+·026	−·004	−·057	+·024	+·021	+·005

TABLE VI (*a*).

Giving the pressure variation from the normal from June 27th to July 5th, arranged to show the westward movement of the disturbance.

	June 27	June 28	June 29	June 30	July 1	July 2	July 3	July 4	July 5
Assam ...	+·111″	+·034″	−·002″	+·045″	+·047″	+·029″	+·055″	+·112″	+·139″
North Bengal	+·115	+·040	−·041	+·049	+·047	+·036	+·064	+·108	+·133
Bihar ...	+·097	+·010	−·049	+·008	+·046	+·071	+·065	+·101	+·082
United Provinces	+·138	+·043	−·009	+·005	+·079	+·062	+·076	+·106	+·075
Punjab ...	+·182	+·074	+·019	+·012	+·036	(?) −·005	(?) +·077	+·123	+·107
Srinagar	+·172	+·074	−·002	+·045	+·041	−·003	+·015	+·065	+·046
Leh ...	+·153	+·073	+·053	+·070	+·059	+·007	+·017	+·017	000

Table VI (*a*) shows that on the 27th there was a large excess in pressure over the whole of Northern India and that the excess was greatest in the Punjab and Kashmir. During the two following days this excess disappeared except at Leh and before the end of the period covered by the table the old excess pressures were restored except at the high level stations. Leh which is the highest of all the hill stations given in the Indian Daily Weather Report was the only station on the 4th and 5th July, for which pressure was not in moderate to large excess.

The westward progress of the temperature change is clearly shown by tables VII (*a*) and VIII (*a*). The rapid fall of temperature, which began on June 29th in Assam is most marked in North Bengal on the 30th, in Bihar on July 1st, in the United Provinces on the 2nd and 3rd, in the Punjab on the 2nd to 4th, and in Kashmir on the 5th.

TABLE VII (*a*).

Giving the temperature change daily from June 27th to July 5th, arranged to show the westward movement of the disturbance.

	June 27	June 28	June 29	June 30	July 1	July 2	July 3	July 4	July 5
Assam ...	+2·4°	−0·2°	**−2·7°**	−3 2°	**+3·3°**	+1·3°	+0·8°	+0·5°	−1·6°
North Bengal ...	+2·5	−1·2	−1 8	**−2·3**	−1·6	**+4·4**	−0·2	−1·5	+1·8
Bihar	−0·6	+0 6	−0·3	−0·5	**−5·2**	−1·3	−2 6	**+1·7**	−0·3
United Provinces	+1·2	+1·9	+0·6	+2·4	−1 7	**−4·0**	−5 3	**+0·6**	−0·8
Punjab ...	+2·5	+3·3	+2 2	+3·2	+1·0	**−6·4**	−3·1	−4·9	**+2·9**
Srinagar, etc. ...	+0·5	+4·5	+3·0	+0 7	+0 4	0·0	−1·6	−1·5	−4·7

TABLE VIII (*a*).

Giving the temperature variation from the normal from June 27th to July 5th, arranged to show the westward movement of the disturbance.

	June 27	June 28	June 29	June 30	July 1	July 2	July 3	July 4	July 5
Assam ...	+0·8°	+0·3°	−2·0°	**−5·7°**	−2 9°	−0 5°	+0·7°	+0·4°	−0·9°
North Bengal ...	+ 2 2	+1·2	−0·8	− 3·1	**−5·5**	−0·7	−1·3	−2·7	−0·4
Bihar ...	+ 6·9	+7·8	+7·8	+ 7·3	+2·6	**+1·4**	**−1·2**	+0 5	+0·4
United Provinces	+ 4·6	+6·9	+7·8	+10·4	+8·8	+4·9	**−0·2**	+0 5	−0·3
Punjab ...	− 2 9	+0·7	+3·2	+ 6·7	+8·0	+1·8	−1·2	**−5·9**	−3·1
Srinagar ...	− 6·5	−1·9	**+2·1**	+ 1·2	+1·9	**−1·3**	**−4·4**	**−2·0**	**−5·1**
Leh ...	−11·0	−3·6	−0·6	− 0·0	**−1·0**	−1·4	+1·1	**−2·1**	**−5·7**

From Table VIII (*a*) it can be seen that the lowest temperature in Assam was on June 30th, in North Bengal on July 1st, in Bihar and the United Provinces on the 3rd, in the Punjab on the 4th, and in Kashmir on the 5th. The very low temperatures which are shown at Srinagar and Leh on the 27th were connected with conditions, then prevailing in Western India, and have no connection with the disturbance or series of disturbances which I have been discussing.

A very striking feature of Table VIII (*a*) is the large fall of temperature in Northern India between June 30th and July 4th. In the United Provinces the change was from an excess of 10° on the 30th to a small defect on the 3rd, and in the Punjab from excess of 8° on July 1st to defect of 5°·9 on the 4th.

TABLE IX (*a*).

Rainfall. (*June 27th to July 4th*).

	No. of Stations.	June 27	June 28	June 29	June 30	July 1	July 2	July 3	July 4
Assam ...	5	3·10	2·47	**6·28**	**8·06**	0·89	5·59	0·04	3·91
North Bengal ...	7	2·12	6·54	**10·68**	**14·28**	2·20	0·10	3·85	3·77
East Bengal ...	7	7·37	0·14	1·60	**26·41**	3·92	9·46	2·10	6·70
South-West Bengal	9	0·93	0·36	0·37	**2·51**	**1·72**	0·01	2·09	16·31
Bihar	13	0·64	...	...	2·02	0·67	**8·85**	2·78	2·24
United Provinces...	12	...	...	...	...	0·79	**3·14**	**4·46**	**7·01**
Punjab ...	6	...	...	...	...	1·81	0·47	**3·12**	1·56
Simla Hills ...	5	0·04	...	...	...	0·17	0·85	**6·49**	**5·92**
Kashmir ...	6	0·07	...	...	0·62	0·49	0·35	0·46	0·91
Darjeeling ...	...	0·04	0·85	0·26	1·69	0·02	0·35	1·49	...
Cherrapoonjee ...	...	...	0·51	3·68	4·66	0·15	0·05	1·22	5·61
Orissa ...	4	...	...	...	...	**8·76**	1·12	0·07	0·46
Circars ...	4	0·35	0·44	...	...	1·60	**7·01**	...	...

TABLE X (*a*).

Rainfall.

	No. of Stations.	Before 30th June.	30th June.	After 30th June.	Total.
Assam ...	5	11·85	8·06	10·43	30·34
North Bengal ...	7	19·34	14·28	9·92	43·54
East Bengal ...	7	9·11	26·41	22·18	57·70
South-West Bengal	9	1·66	2·51	20·13	24·30
Bihar ...	13	0·64	2·02	14·54	17·20
United Provinces	12	.....	.....	15·40	15·40
Punjab ...	6	.....	.....	6·96	6·96
Simla Hills ...	5	0·04	.....	13·43	13·47
Kashmir ...	6	0·07	0·62	2·21	2·90
Darjeeling ...	...	1·15	1·69	1·86	4·70
Cherrapoonjee ...	...	4·19	4·66	7·03	15·88
Orissa ...	4	.....	.....	10·41	10·41
Circars ...	4	0·79	.....	8·61	9·40

In Tables IX (*a*) and X (*a*), I have given the rainfall in Northern India, for the period June 27th to July 4th. They are similar, to those which precede as to divisions of the country. The figures I have obtained by merely adding up the rainfall recorded at the various stations in each division and the stations which I have taken, are those given in the *Indian Daily Weather Report*. In the first column of each of these Tables the number of stations is given so that the average rainfall for each day or for a group of days so far as it depends on the records of the stations selected can be obtained by dividing by that number. The heavy rainfall in East Bengal on the 27th June, has no connection, so far as I can see with the general disturbance which culminated in the down-pour in East and North Bengal on the 30th. Setting that item aside it will be seen that in Assam and North Bengal, the rainfall steadily increased between the 27th and the 30th, and that the dates of heaviest rainfall were the 29th and 30th. Proceeding southward from North Bengal the dates of heaviest rainfall are East Bengal June 30th, South-West Bengal June 30th and July 1st, Orissa July 1st, and the

Circars July 2nd. Going westward we see that before June 30th, Bihar was practically rainless, and that there was no rain in the United Provinces, Punjab, and the Simla Hills, until July 1st. The dates of heaviest falls are July 2nd in Bihar, the 2nd and 3rd in the United Provinces, the 3rd in the Punjab, and the 3rd and 4th in the Simla Hills.

In Table X (*a*) I have merely added together the columns for the days 27th, 28th, and 29th, with the heading "before 30th June" and the columns for the days July 1st to 4th with the heading "after 30th June." It will be seen that the heaviest falls occurred before the 30th June in Assam and Bengal, and after the 30th June in Lower Bengal, Orissa, the Circars and over the whole of North-Western India.

In addition to the provinces and divisions in the Table, I have given the rainfall at Darjeeling and Cherrapoonjee. The rainfall at these two stations agrees only partially with what is given for the plains of Bengal and Assam; and there is a striking difference between the falls at these places for the two disturbances. With the June storm, rainfall was comparatively light at both Darjeeling and Cherrapoonjee, while in August it was very heavy at both.

There appears to me to be no want of evidence, in the above Tables, in favour of the view that an atmospheric disturbance invaded India from the north-east, at the end of June. I may, however, give one or two further items of information showing the south-westward direction of progress over Bengal. They are only stray items, but they will indicate to some extent how the meteorological record might be improved, if there were some fore-knowledge of coming events and of the direction from which change should be looked for.

As the disturbance advanced over Bengal, thunderstorms probably occurred at places in succession. If so the fact has not been recorded. But I saw in the newspapers that a local storm of great severity had occurred between Nalhati and Rampur Hât, on June 29th, and I have ascertained that the hour when it overturned a train on that part of the E.I. Railway was between 3 and 4 o'clock in the afternoon. I personally observed the changes, as the wave passed over Calcutta, on the morning of the 30th and the traces of the self-recording apparatus, at the Alipore Observatory, show that it began about 4 A.M. on that date and was practically over by 10 A.M. When the weather was becoming more settled at Calcutta, that is about 10 A.M. I received a telegram from the observer at Saugor Island that weather was very unsettled there, that the barometer had fallen two-tenths of an inch, and that the wind was blowing 44 miles an hour. The following day I heard from a Calcutta resident who had just arrived from Madras that while the train on the East Coast Railway was passing through Orissa on the

night of the 30th, they had experienced very severe thunderstorms, with most vivid lightning. Though these are only stray facts, they indicate very clearly how the disturbance was advancing.

TABLE.

Place.	Hour and date of local storm.
Rampur Hât	3-30 P.M., June 29th.
Calcutta	6-0 A.M. to 8 A.M., June 30th.
Saugor Island	About 10 A.M., June 30th.
Orissa	About midnight, June 30th.

The following Table gives the hourly changes of pressure from the barograph at Alipore Observatory, on June 30th. Hourly pressure at Alipore corrected for instrumental errors and reduced to 32° Fah.

June 30th.	Actual pressure.	Approximate normal.	Change.
4 A.M.	29·539″	29·548″	−·009″
5 „	·563	·549	+·014
6 „	·588	·560	+·028
7 „	·633	·576	+·057
8 „	·597	·592	+·005
9 „	·646	·602	+·044
10 „	·658	·613	+·045
11 „	·697	·598	+·001
12 „	·678	·585	−·007

The Table shows that at 4 A.M. pressure was normal, that considerable oscillations occurred between that hour and 11 A.M. (a rise followed by a fall) and that at noon the difference from the normal was the same as it had been at 4 A.M. The general appearance of the part of the trace from which the above measurements were taken is irregular and jagged without any marked sign of a depression, that is, the trace is of the kind characteristic of the passage of nor'westers in the hot season.

The temperature changes show a steady decline from 4 A.M. until noon. The change, though not quite regular, is not of the sudden cha-

racter of the fall accompanying thunderstorms. It was continuously falling throughout the period and that at a time, it may be observed, when in ordinary weather temperature is rising with the advancing day.

Table giving temperature changes at Alipore observatory in degrees Fahrenheit.

	On June 30th.	Approximate normal.	Difference.
4 A.M.	85°·2	80°·7	+4°·5
6 „	83·0	81·1	+1·9
8 „	82·8	83·5	−0·7
10 „	79·5	86·2	−6·7
12 „	78·5	87·5	−9·0

The last column of the Table shows the large change of temperature which occurred between 4 A.M. and noon on the 30th June at Calcutta. It also shows indirectly how scanty, comparatively, would have been the information if the record had been limited to what is usually noted at 8 A.M. The temperature at that hour was practically normal.

Storm of August 11th.

The Tables containing the information for the August disturbance have been prepared in the same way as those for the preceding storm and are given below in the same serial order for purposes of comparison. I stated in discussing the earlier storm that the pressure changes give an imperfect indication of the line of advance of the wave of change. From Tables I (*b*), II (*b*), V (*b*) and VI (*b*) it will be seen that the fall of pressure began in North Bengal on August 9th, that it extended southward over Bengal Proper and Orissa and westward as far as the Punjab on the 10th; and that while pressure was beginning to recover in North-East India on the 11th it was still falling in the United Provinces, the Punjab and Kashmir. The fall on the 11th, was very rapid at Teheran (·175″) and Ispahan (·150″), showing that the centre of the wave had passed westward beyond the Indian region. The rapidity of this westerly movement is very little less than that of the earlier disturbance, and would probably have eluded observation if it had not been for the larger fall. The fall is first shown on the 9th in the north-east, and within 48 hours has passed far beyond the western boundary of India. The movement is also shown by the recovery

which began on the 11th in Assam, and North Bengal, was rapid in North-Western India on the 12th and at Jask, Quetta, etc., on the 13th.

TABLE I (*b*).

Giving the pressure changes daily from August 8th to 14th, arranged to show the southward movement of the disturbance.

	August 8	August 9	August 10	August 11	August 12	August 13	August 14
Assam ...	+·040″	+·004″	−·043″	+·019″	+·022″	−·019″	−·019″
North Bengal ...	+·057	−·025	−·087	+·037	+·059	−·018	−·010
East Bengal ...	+·067	+·003	−·061	−·003	+·052	−·020	−·025
South-West Bengal	+·050	+·006	−·065	+·050	+·039	−·025	−·018
Orissa ...	+·051	+·044	−·043	+·013	+·052	−·024	−·043
Circars ...	+·049	+·054	−·009	−·017	+·049	−·022	−·051
Akyab ...	+·062	+·028	−·021	−·043	+·008	+·011	−·062
Diamond Island...	+·055	+·014	−·016	−·051	+·019	−·003	−·057

Winds at Diamond Island varied between south-west and west-north-west and showed no signs of becoming easterly.

TABLE II (*b*).

Giving the pressure variation from the normal from August 8th to 14th, arranged to show the southward movement of the disturbance.

	August 8	August 9	August 10	August 11	August 12	August 13	August 14
Assam ...	+·056″	+·052″	−·007″	+·004″	+·028″	+·010″	−·013″
North Bengal ...	+·075	+·040	−·051	−·019	+·034	+·016	+·006
East Bengal ...	+·079	+·075	+·006	000	+·053	+·027	+·003
South-West Bengal	+·066	+·071	000	+·043	+·080	+·049	+·028
Orissa ...	+·060	+·104	+·053	+·069	+·114	+·087	+·041
Circars ..	+·032	+·085	+·072	+·054	+·102	+·078	+·024
Akyab ...	+·066	+·091	+·066	+·020	+·025	+·032	−·034
Diamond Island...	+·055	+·066	+·047	−·007	+·010	+·004	−·055

Table III (*b*).

Giving the temperature changes daily from August 8th to 14th, arranged to show the southward movement of the disturbance.

	August 8	August 9	August 10	August 11	August 12	August 13	August 14
Assam ...	−3·3°	−0·7°	**−2·8°**	**−2·9°**	−0·6°	+3·5°	+2·8°
North Bengal ...	−0·6	−1·9	−0·4	**−3·4**	−1·1	+3·3	+1·5
East Bengal ...	−1·6	+0·2	+0·6	**−3·9**	−0·7	+3·9	+0·7
South-West Bengal	−0·3	−0·6	+0·5	**−5·6**	+1·1	+4·5	+0·2
Orissa ...	−1·4	+0·2	+0·9	**−1·8**	−0·3	+1·8	+1·3
Circars ...	+1·8	−0·4	−1·4	+1·0	0·0	−0·1	+1·2
Akyab ...	+1·0	+2·5	+0·8	+0·2	−0·7	−2·8	+1·5

Table IV (*b*).

Giving the temperature variation from the normal from August 8th to 14th, arranged to show the southward movement of the disturbance.

	August 8	August 9	August 10	August 11	August 12	August 13	August 14
Assam ...	−0·7°	−0·8°	−3·7°	**−6·4°**	**−6·8°**	−3·4°	**−1·3°**
North Bengal ...	+2·1	+0·4	+0·1	**−3·2**	−4·0	−0·9	+0·2
East Bengal ...	+0·5	+0·7	+1·3	**−2·5**	**−3·2**	+0·6	+1·2
South-West Bengal	+2·4	+2·0	+2·5	**−3·1**	**−2·1**	+2·3	+2·6
Orissa ...	+0·8	+1·1	+2·2	+0·5	+0·2	+1·4	+3·6
Circars ...	+3·7	+3·3	+1·9	+3·0	+2·9	+2·9	+4·1
Akyab ...	−0·2	+2·4	+3·2	+3·5	+2·7	−0·1	+1·5

TABLE V (*b*).

Giving the pressure change daily from August 8th to 14th, arranged to show the westward movement of the disturbance.

	August 8	August 9	August 10	August 11	August 12	August 13	August 14
Assam ...	+·040″	+·004″	−·043″	+·019″	+·022″	−·019″	−·019″
North Bengal ...	+·057	−·025	−·087	+·037	+·059	−·018	−·010
Bihar ...	+·036	+·012	−·078	−·009	+·102	−·022	−·017
United Provinces	+·004	+·060	−·101	−·077	+·144	+·024	−·036
Punjab ...	−·025	+·056	−·085	−·103	+·212	+·041	−·040
Srinagar, etc. ...	−·007	−·008	−·084	−·087	+·130	+·089	+·002

TABLE VI (*b*).

Giving the pressure variation from the normal from August 8th to 14th, arranged to show the westward movement of the disturbance.

	August 8	August 9	August 10	August 11	August 12	August 13	August 14
Assam ...	+·056″	+·052″	−·007″	+·004″	+·028″	+·010″	−·013″
North Bengal ...	+·075	+·040	−·051	−·019	+·034	+·016	+·006
Bihar ...	+·045	+·048	−·038	−·041	+·050	+·029	+·010
United Provinces	+·027	+·080	−·022	−·100	+·035	+·054	+·015
Punjab ...	000	+·046	−·041	−·153	+·035	+·078	+·040
Srinagar ...	+·054	+·025	−·031	−·130	+·055	+·137	+·106
Leh	+·059	+·038	−·047	−·145	−·052	+·049	+·045

It is not a matter of much importance in connection with this paper, whether local variations occurred while the above changes were in progress. What I have attempted is to establish the general progress of the disturbance, pointing out that the part of India first affected was the north or north-east and that from the place of first contact the line of advance was southward and westward. The Tables for the second disturbance are very similar to those of the earlier one

and I propose commenting very briefly on the figures they contain. Tables III (*b*) and IV (*b*) give the temperature changes, and variation indicating the southward movement, and VII (*b*) and VIII (*b*) are similar Tables for the westward movement.

TABLE VII (*b*).

Giving the temperature changes daily from August 8th to 14th, arranged to show the westward movement of the disturbance.

	August 8	August 9	August 10	August 11	August 12	August 13	August 14
Assam ...	−3·3°	−0·7°	−2·8°	−2·9°	−0·6°	+3·5°	+2·8°
North Bengal ...	−0·6	−1·9	−0·4	−3·4	−1·1	+3·3	+1·5
Bihar ...	+0·7	−1·0	−0·7	−2·8	−0·2	+3·0	+0·1
United Provinces	+1·8	−2·5	−0·4	+2·0	−1·4	+1·0	+1·5
Punjab ...	+3·1	+0·2	−1·9	−0·9	−5·6	−2·6	+3·3
Srinagar, etc. ...	+2·5	+1·1	+0·3	−3·0	−7·8	−5·4	−0·2

TABLE VIII (*b*).

Giving the temperature variation from the normal from August 8th to 14th, arranged to show the westward movement of the disturbance.

	August 8	August 9	August 10	August 11	August 12	August 13	August 14
Assam ...	−0·7°	−0·8°	−3·7°	−6·4°	−6·8°	−3·4°	−1·3°
North Bengal ...	+2·1	+0·4	+0·1	−3·2	−4·0	−0·9	+0·2
Bihar ...	+2·9	+1·9	+1·3	−1·4	−1·2	+1·8	+1·8
United Provinces	+2·4	−0·1	−0·6	+1·5	+0·2	+1·2	+2·8
Punjab ...	+7·0	+7·2	+5·5	+4·9	−1·0	−3·5	−0·1
Srinagar ...	+4·1	+4·9	+4·9	+5·2	−3·4	−10·5	−10·7
Leh ...	+0·9	+2·3	+2·0	−1·4	−7·5	−14·9	−9·7

The southerly movement is less marked than was the case in June. The fall of temperature began in Assam on the 10th, it extended to Bengal Proper on the 11th, and there was a slight fall in Orissa also on that date. But unlike the earlier disturbance, mean temperature did not fall below the normal in Orissa, and in the Circars temperature continued high throughout the period.

From Tables VII (*b*) and VIII (*b*) it may be seen that the fall of temperature which began in Assam on the 10th, and North Bengal on the 11th, occurred in Bihar on the 11th, and in the United Provinces, Punjab, and Kashmir on the 12th. From Table VIII (*b*) in which the variation from the normal is given it may be seen that there was a very large defect in Assam on the 11th and 12th, and at Srinagar and Leh on the 13th and 14th.

The rainfall Tables IX (*b*) and X (*b*) show as before the heavy rainfall in Bengal Proper on the 11th, the heavy rain in Assam on the previous day the 10th, and that the days of heavy rainfall in the west of India were the 12th and 13th.

TABLE IX (*b*).

Rainfall (August 8th to 14th).

	August 8	August 9	August 10	August 11	August 12	August 13	August 14
Assam ...	3·28	7·07	**18·73**	**12·40**	**13·38**	1·97	0·70
North Bengal ...	2·09	3·24	**15·53**	**29·43**	9·38	2·19	4·26
East Bengal ...	2·63	6·79	1·62	**28·71**	9·03	4·04	1·15
South-west Bengal	1·17	0·55	3·33	**15·11**	2·28	0·93	0·25
Bihar ...	1·80	6·55	5·19	**12·94**	3·10	4·44	0·92
United Provinces	7·77	1·38	5·24	1·32	—	0·32	0·01
Punjaub ...	—	—	0·05	**1·31**	**1·81**	0·32	—
Simla Hills ...	0·16	7·21	1·09	2·06	**8·62**	**3·59**	0·16
Kashmir ...	0·43	—	0·03	1·05	**2·49**	1·02	0·52
Darjeeling ...	0·79	0·12	1·01	**7·91**	1·35	0·17	0·11
Cherrapoonjee ...	2·09	4·08	**28·69**	**22·71**	4·25	1·69	0·18

TABLE X (*b*)

– *Rainfall.*

	No. of Stations.	Before 11th August.	11th August.	After 11th August.
Assam	5	29·08	12·40	16·05
North Bengal	7	20·86	29·43	15·83
East Bengal	7	11·04	28·71	14·22
South-west Bengal	9	5·05	15·11	3·46
Bihar	13	13·54	12·94	8·46
United Provinces	12	14·39	1·32	0·33
Punjaub	6	0·05	1·31	2·13
Simla Hills	5	8·46	2·06	12·37
Kashmir	6	0·46	1·05	4·03
Darjeeling	—	1·92	7·91	1·63
Cherrapoonjee	—	34·86	22·71	6·12
Orissa	4	—	—	—
Circars	4	—	—	—

It may also be seen that the rainfall was much more heavy at Darjeeling and Shillong than in June. At Darjeeling on the 11th nearly 8 inches fell, more than double the total fall for the three preceding and the three following days put together. At Cherrapoonjee 50 inches fell on the 10th and 11th taken together.

The only sensational incidents I have heard of in connection with this later storm were landslips in the Hills and heavy flooding of the rivers as the rainfall extended westward along the Himalayas.

If a comparison be made of the two sets of Tables, it will be seen that in many important respects the resemblance is as striking as two sets of meteorological Tables could almost be expected to be. The wave of pressure change in each case passed very rapidly, so much so that it is difficult to show the line of advance by the sequence of changes. The fall and the recovery were much greater in Western India in the latter than in the former. In each case the fall of temperature can be traced from East to West, but in the June storm the sequence is more complete

because of the change from intense hot weather in Bihar, the United Provinces and the Punjaub, to the cooler weather of the monsoon season. Though the intermediate changes of temperature are less marked in August, there is abundant evidence of the line of advance of the wave of change; and the low temperature in Assam on the 11th and 12th, followed after an interval of two days by what may be called wintry weather in Kashmir, affords a succession of events which it would be difficult to account for, except on the supposition of a westward-moving atmospheric disturbance. But in my opinion the most striking similarity in connection with these two disturbances is afforded by the heavy general rainfall in Bengal Proper on the 30th June and the 11th August. In the latter case particularly, it is obvious that no disturbance entered Bengal from the Bay, which had been singularly calm throughout the week from the 8th to the 14th August. The wind direction at Diamond Island was westerly throughout the period, and velocity day by day was below the average for the season. In both cases, as shown by the following Table, there was considerable increase of wind force at Saugor Island; but the direction continued south-westerly, showing that the change was due to some influence to the north, and the record of the Pilot Brig shows that the strong winds extended to no great distance southward from the Bengal coast.

Table giving the wind force and direction at Saugor Island during the two periods of disturbed weather.

June.	Daily velocity in miles.	Wind direction at 8 a.m.	August.	Daily velocity in miles.	Wind direction at 8 a.m.
27	312	S.S.W.	8	360	S.W.
28	408	S.S.W.	9	504	S.S.W.
29	576	S.S.W.	10	768	S.
30	840	S.S.W.	1	394	W.S.W.
July. 1	360	W.S.W.	12	288	S.W.
2	456	S.W.	13	384	W.S.W.
3	384	S.W.	14	120	W.N.W.

One difference which may be noted, as shown by the above Table, is that the highest velocity in the earlier disturbance occurred at Saugor

Island between the 10th and 11th, that is along with the heavy rainfall in Bengal Proper, whereas in the later disturbance it was between the 9th and 10th, or before the heavy rainfall. In other respects the resemblance is very striking, and the Table shows that with the fall of pressure in the north, the south-westerly wind increased and continued to increase until the recovery of pressure was complete. There is no sign with either disturbance of the northerly winds which invariably accompany a disturbance over the Bay.

Mr. C. C. Collingwood who was in command of the P.V. "Alice" at the Sandheads informs me that, from the 29th June to the 1st July, the brig was under way all the time, and that work went on as usual; also that there was very little sea-set. The weather was bright and clear, except from 8 A.M. of the 30th June to 10 A.M. of the 1st July. The following extract from the log for June 30th is given in full, because it shows the time at which the disturbance which passed over Bengal south-westward commenced at the Pilot Brig.

Extract from the log of the P.V. "Alice" stationed at the Sandheads June 30th.

Hour.	Pressure.	Temperature.	Wind direction.	Wind force.	Weather.
2	29·66″	88°	S.W.	3	bc
4	·63	88	S.W. × W.	4	bc
6	·67	88	S.W.	3·4	bc
8	·73	89	S.W.	3	oc
10	·78	82	S.W.	1·2	ocqlt
12	·76	80	W.N.W.	3·4	oc
14	·74	81	E.S.E.	1	o
16	·66	84	S.S.E.	1	o
18	·66	84	S.	3	ocqlt
20	·68	83	W.	3·5	ocl
22	·72	83	S.W.	2·3	ocl
24	·68	83	S.W. × W.	1·2	ocd

The change of temperature shows that the disturbance which had begun at 4 A.M. in Calcutta, reached the Pilot Brig between 8 and 10 A.M., and the column giving wind force shows that nothing more than a moderate breeze was experienced. The increase of cloud began about 8 A.M., and the sky was more or less overcast during the day.

Part III.

In the preceding, which I have called Part II, I have considered only the weather changes, as they are indicated chiefly by the 8 A.M. observations from day to day during the period of disturbance. These are of sufficient interest to justify their separate consideration. But the two storms, which in what follows I shall represent by the dates June 30th and August 11th, appear to me to have caused a change so striking in the atmospheric conditions over Northern India, that those dates become punctuation marks in the monsoon season of 1902. The expression "punctuation marks" inadequately conveys my full meaning, and I would perhaps indicate more clearly the importance of the changes which then took place if I say that new chapters begin with those dates. It is impossible in the space which I now have at my disposal to go fully into the wider question which I am attempting to open out, even if I had the material ready. But I will indicate briefly the general run of the argument in order to form a line of connection with some future effort in this direction.

A study of the monsoon season of 1902 falls naturally into four periods:—

A—From the beginning up to the end of June, that is until the first Himalayan storm occurred.

B—From the 30th June to the 11th August, that is, from the first Himalayan storm up to the beginning of the second.

C—The three to four weeks which follow the 11th August, and during which the 'remarkable series of storms' moved from the Bay of Bengal north-westward to the extreme west of India.

D—The remaining part of the season, which I consider began with the storm which early in September broke up over the south-west of the Province instead of moving westward as the various members of the 'remarkable series' did.

During each of these periods we have a well-defined behaviour of the cyclonic storms, and a well-defined distribution of rainfall. Also the connection between the line of advance of the storms and the prevalence of monsoon conditions is so striking that the study of the

monsoon is reduced to an enquiry why a cyclonic storm should move from the Bay of Bengal in one direction at one time of the year, and in another direction a week or two later; why it may be for several weeks at a time the prominent features of these storms are, more especially as regards the line of advance, repeated with but little variation; and why there should come without warning by ground level instruments a marked change in the line of advance.

In ordinary years cyclonic storms move westward, or slightly to the north of west [1] from the beginning of the monsoon season, and while they follow the usual direction there is no want of rain in any part of Northern India. During the past five years cyclonic storms have been very far from following the usual course, that is the course which the previous fifteen or twenty years' experience had shown to be the usual course. For instance, in 1899 the recurving was very marked, especially in August and September; and there being no 'remarkable series of storms' such as occurred during the past year, the crops failed over wide areas in Western and Central India. Several storms developed in 1899 over the Bay at the most critical time, that is August, and began to move westward; but in every case their advance was checked over the Central Provinces, and they recurved towards Bengal, where in consequence rain fell in abundance. Contrast the past year with 1899, and the main difference will be found in the behaviour of the cyclonic storms in the latter part of August and the early part of September. No one who is interested in crops and rainfall can have forgotten how critical the condition had become in the west of India in August 1902; and how it was a question of days whether or not there would be a repetition of the disasters of 1899; and that just when it was not too late the change came, and came with the first of that 'remarkable series of storms' which was in the west of the Bay on the 19th of August and over the north-west dry area and Guzerat on the 22nd. Two more storms followed the same course at intervals of about a week, crossing the area of drought and giving plentiful rainfall where it was most needed.

The difference between the years 1899 and 1902 is that the storms of the second-half of August and first part of September in former

[1] In page 173 of the Hand-Book of Cyclonic Storms in the Bay of Bengal, Second Edition, Sir John Eliot says regarding cyclonic storms in July :—"The charts shew that all the 39 storms which formed in the Bay during this month, in the period 1877-99, marched in west or west-north-west directions across the north-west angle of the Bay; and the centres of all with about six exceptions crossed the coast between Saugor Island and Gopalpur. In the great majority of cases they afterwards advanced across the head of the Peninsula into Sind, Guzerat or Rajputana.

year recurved over Central India and in the latter year they did not.

And so it appears to me that this matter of the motion of cyclonic storms over Northern India is one urgently requiring explanation, and that so long as it is unknown in what direction a storm will move in the immediate future so long will the distribution of rainfall be a subject of speculation only. So great a difference as we find between the directions of motion of storms in the four periods of the past monsoon season must be due to well-defined causes which it must be possible to determine. The only point on which I feel any certainty is that these causes will not be determined by ground level observations. To me it appears much more likely that they are connected with overhead conditions, and the past season indicates that the cause may be found in an overhead current from the west, that is in its height and strength. This current is the main current over Northern India during the cold season and the early part of the hot season. It retreats upwards with the approach of the monsoon season and my opinion is that monsoon conditions cannot be established in Northern India so long as its strength is unimpaired.

The only effects which I am aware of as giving some indication of the strength of that current late in the season are the occurrence of late snowfall in the hills, and of late nor'westers in Bengal such as were experienced in June of last year. It is well known that for some years late snowfall in the hills has been put forward as indicating the late arrival of the monsoon, but I am not aware that there has been any connection established between the snowfall and the strength of the westerly overhead current. The reason for this doubtless is the great difficulty always experienced in any attempt to investigate the higher levels of the atmosphere—a difficulty which is not to any extent removed by the establishment of observatories on ranges of high hills. It has come to be recognised by meteorologists that a high level observatory must be placed on the top of an isolated peak; otherwise the local irregularities of the ground, such as the spurs and valleys of the Himalayas, cause deviations in the record and the result is misleading.

I have divided the monsoon season of 1902 into four periods—June 30th being the division between the first and second and August 11th between the second and third of these periods—and I will now state generally the line of advance of depressions from the Bay of Bengal during these periods.

Period A.

In May a depression entered Burma, moving in a north-easterly direction, the usual one at that time of the year. In June there was at

times a tendency to the formation of depressions over the north of the Bay, but it was temporary except about the 11th June, when the slight depression which then formed moved northwards into Bengal proper. The usual direction in which depressions advance in the middle of June is north-westward, and it is a fact worth noting that last year the depression which in ordinary years would have been followed by monsoon conditions over north-western India, moved into North Bengal instead, and that the monsoon weather was confined to Bengal Proper and Assam.

Period B.

Two storms occurred during this period. They followed an almost identical course into Central India and then recurved towards the Kumaon Hills.

The following extracts from the *Indian Daily Weather Report* give the opinions recorded at the time regarding the change of motion and the place where it occurred.

1st storm of Period B.

July 17th. "The cyclonic storm will probably continue to advance in a west-north-westerly direction."

July 18th. "The cyclonic storm from the Bay instead of continuing a westerly course has been almost stationary, and is apparently recurving to the north."

July 19th. "The storm is apparently advancing towards the Kumaon Himalayas."

It may be noted that the change of direction which occurred between the 17th and 18th was not anticipated, showing that the information supplied by the ground level observations was not sufficient to settle the direction beforehand.

2nd storm of Period B.

July 30th. "The cyclonic storm has continued to advance slowly in a west-north-westerly direction and is now apparently central near Nowgong."

July 31st. "The cyclonic storm in the Central India Plateau has been almost stationary during the past day, which may be an indication that it is about to change its direction of advance.

Aug. 1st. "The cyclonic storm is apparently advancing to the Kumaon Himalayas."

The course is shown by the above extracts to be the same as in the preceding storm and it is also seen that the experience gained from the

earlier storm made it possible on July 31st to anticipate to some extent the change of direction.

Period C.

A single extract from the *Indian Daily Weather Report*, of September 4th, will give the necessary information regarding the storms of this period.

"The present storm is the third of a remarkable series of storms which have formed in the Bay since the 19th August and have followed an almost identical course."

The first storm was over Guzerat or the north-west dry area, on August 22nd, the second on August 28th, and the third on September 3rd.

Period D.

What appeared to be a fourth in the above series was over the north-west of the Bay, on September 5th, and was expected to advance into the east of the Central Provinces during the next thirty-six hours, but it moved northwards, and on September 8th and 9th became diffused over West Bengal and the adjacent part of Central India. The following extracts are taken from the *Indian Daily Weather Report* because they support my contention already expressed, that recurving or in fact the direction of motion at any time is not directly indicated by the ground level observations of the day.

September 6th.—"The storm at the head of the Bay is likely to advance into the east of the Central Provinces during the next thirty-six hours and will probably give moderate to heavy rain to Orissa, Chota Nagpur, West Bengal, and the east of the Central Provinces. Weather may become feebly unsettled in Kashmir within the next day or two."

(Sd.) J. Murray,
Offg. Meteorological Reporter to the Govt. of India and Director-General of Indian Observatories.

September 7th.—"The storm at the head of the Bay has hardly changed in position during the past twenty-four hours and now shows a tendency to advance northwards into Bengal in which case rainfall will increase in Lower Bengal."

September 8th.—"The cyclonic storm in Bengal will probably continue to advance in the same general northerly direction and give moderate to heavy rain in East and North Bengal and Assam."

The next storm in the Bay began towards the end of the third week of September and was well defined over the north-west angle on the 24th. From there it moved north-westward into Chota Nagpur, then northwards, and on the morning of the 26th was recurving towards

the Darjeeling Hills. It broke up on reaching the Himalayas, causing heavy rainfall in the eastern part of the range. A slight residual depression moved eastward into Assam.

It will be seen from the above extracts and remarks that the storms from the Bay during the monsoon season fall clearly into the four classes I have formed. Two in period (*A*) moved northwards; two in period (*B*) moved in the usual west-north-westerly course, but recurved over Central India towards the Kumaon Himalayas; three in period (*C*) moved west-north-westward, and without recurving passed over Guzerat and other parts of Western India where rain was much needed; and that the two storms in period (*D*) moved into Bengal; thus showing that, whatever the determining cause of the line of advance of these storms may be, it was in September becoming similar to what obtained in period (*A*) that is at the beginning of the season.

The question therefore is what cause would be sufficient to account for the change of motion in its various degrees shown by these storms of the past monsoon season. I know of only one, and that is the westerly wind overhead which is believed to cease before the monsoon commences, but which may continue in the higher levels after it has ceased near the ground. I was watching this wind very carefully last year, and believe it still existed over Lower Bengal as late as the last week of June, because typical nor'westers occurred about that time. I believe also that the north-westerly wind returned earlier than usual at the end of the season, and was stronger than usual or in some other way differed from what it is in ordinary years, and my reason for thinking so is that nor'westers occurred in October in Western Bengal, a most unusual event.

Another question is, why should the two storms from Central Asia, which I have discussed in the second part of this paper, influence that westerly current. I am unable to say why it should be so, but I think there can be no doubt, but that seasonal currents are often materially altered by what for want of a better word I will call the shock of a storm. The Rangoon cyclone early in May supplies an example of such a change. An examination of weather charts for April and May last year will show that the wind directions on the Burma coast were northerly up to the occurrence of that storm and that afterwards they had generally the south-westerly direction usual in the monsoon season.

The permanent change in the wind system on the Burma coast then produced is none the less instructive, because the north-westerly winds in April and May are believed to be a continuation of the very current which appears to me to have so much to do with the advent of the monsoon in different parts of Northern India, and in reasoning that the

storms from Thibet influence the overhead current so as to render the advent of the monsoon possible in the first case as far west as Central India and the Kumaon Himalayas, and in the second case to the extreme west of the empire I am making an assumption in support of which I believe numerous examples such as the Rangoon cyclone of 1902 can be cited. The influence of these storms from Thibet was in all probability greater in the upper reaches of the atmosphere than is shown by the ground level observations, because in the first place the storms were at a high level to begin with, owing to the Central Asian plateau, and in the second place the Himalayan range was an obstacle to their progress so serious that none but disturbances extending to a great height could have passed over them without complete disintegration.

Before closing I will refer very briefly to the storms which occurred in the Arabian Sea during 1902. They were only three in number. Two occurred in period (*A*), *viz.*, the two Karachi cyclones and they moved in much the same direction as the two storms in that period from the Bay, that is, northward or north-eastward. The third occurred in July and was therefore in period (*B*). That storm appears to me to be very suggestive as to the circumstances in which monsoon conditions may be produced by a cyclonic storm. It entered Guzerat and the part of India which was most in need of rainfall. It, however, ceased to be a well-defined cyclonic disturbance, while still over Guzerat and though, a steep pressure gradient developed shortly afterwards over the whole of North-Western India and there were all the appearances which would suggest a strong inrush of monsoon winds with general rainfall, only a few showers fell and those near the coast. The weather produced by that depression, which was quite as deep as any one of the "remarkable series" in the third period, was dry hot weather, rather than monsoon weather.

The following extracts from the *Indian Daily Weather Report*, during the time of that disturbance will show that what I have stated above is borne out by the daily observations and also that it was difficult if not impossible to forecast the behaviour of the depression as regards the line of advance.

July 6th.—"The low pressure area in the Arabian Sea is apparently still an ill-defined disturbance, and has not yet developed into a cyclonic storm."

July 7th.—"The cyclonic storm in the Arabian Sea is apparently advancing towards the Kathiawar Coast."

July 8th.—"The cyclonic storm in the Arabian Sea crossed the Kathiawar Coast yesterday afternoon and has apparently been almost stationary during the past eighteen hours. Its future course is un-

certain, but the character of the isobars and of the pressure changes, would appear to indicate the possibility of its advancing in a north-westerly direction."

July 9th.—"The cyclonic storm in Guzerat has been almost stationary during the past twenty-four hours."

July 10th.—"The storm in Kathiawar is filling up but will probably continue to give rain in Guzerat, during the next twenty-four hours."

On July 11th no reference is made to the storm which was no longer shown by the ground observations and rainfall in India was confined to restricted areas.

The following Table, gives the rainfall in Guzerat, between the 6th and 11th July, and the amount which from the normal Tables was likely to fall during those days:—

	Actual rainfall between 6th and 11th July.	Normal rainfall between 6th and 11th July.
Surat	2·17	3·11
Ahmednagar	0·70	1·91
Bhavnagar	0·65	0·71
Veraval	6·05	0·76
Rajkot	0·70	2·28
Bhuj	1·00	1·18
Deesa	0·32	1·35

It will be seen that Veraval alone received excess rainfall, and that at three other stations, Ahmednagar, Rajkot, and Deesa, rainfall was much in defect.

I have pointed out that the two storms from the Bay in period (*B*) recurved towards the Kumaon Hills, and that the storm from the Arabian Sea filled up in Guzerat after causing rainfall near the coast. In fact, that storm was very similar in its behaviour, to the first storm in period (*D*), which filled up in south-west Bengal, and it is not unlikely, that the filling up was due to similar causes, if these were only known. It may, therefore, be assumed that throughout period (*B*) there was some influence which prevented the advance of cyclonic storms, whether from the Bay of Bengal or from the Arabian Sea, into the north-west

dry area. What change took place, before period (*C*), with its "remarkable series" of storms began, can be matter of surmise only, but I think it is fair to assume that it was not shown by the ground level observations, and that it may have been caused by the disturbance of August 11th, which entered India from Thibet, and which was so clearly shown in its advance along the Himalayan Range.

I may be allowed to explain that I make no claim to have thrown, by this discussion, any light upon the complicated problem of the distribution of monsoon rainfall in Northern India. The connection between cyclonic storms and rainfall has for years been a matter of enquiry. I shall be satisfied if I have even partially succeeded in making out a *primâ facie* case for an extension of meteorological observations to the upper atmosphere, feeling sure as I do that further information in that direction will meet requirements which ground level observations have hitherto failed to satisfy.